Navier-Stokes Computations
of Finned Missiles
at Supersonic Speeds

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Abstract

The U.S. Army Research Laboratory (ARL) is interested in applying state-of-the-art high performance computing tools to predict the aerodynamics of Army shell at angle of attack for a wide range of Mach number from high subsonic to high supersonic. In this paper, the WIND flow solver has been used to study the aerodynamics of two missile configurations. The GridPro grid generation software has been utilized to generate the computational grids. Several aspects of interest concerning the generation of grids for use with WIND and the process of obtaining solutions is discussed. Comparisons are shown between computation and experiment for several turbulence models.

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ABSTRACT

The U. S. Army Research Laboratory (ARL) is interested in applying state-of-the-art high performance computing tools to predict the aerodynamics of Army shell at angle of attack for a wide range of Mach number from high subsonic to high supersonic. In this paper, the WIND flow solver has been used to study the aerodynamics of two missile configurations. The GridPro grid generation software has been utilized to generate the computational grids. Several aspects of interest concerning the generation of grids for use with WIND and the process of obtaining solutions is discussed. Comparisons are shown between computation and experiment for several turbulence models.

1. INTRODUCTION

Researchers in computational fluid dynamics at ARL are interested in investigating a wide array of complex fluid flow problems. These problems include flow around complex bodies, flow at moderate and high Mach number, and flow at moderate to high angles of attack. A recent study examined the predictive capability of several different Navier-Stokes flow solvers applied to the case of an ogive-cylinder configuration at transonic and supersonic flow velocities at 14° angle of attack (Sturek et. al., 1997) . This study extends the previous work by examining the predictive capability of the WIND flow solver to predict flow problems for missiles with fins at angle of attack and moderate Mach number.

The WIND flow solver has numerous capabilities that make it potentially attractive for computational researchers. Among these features are the numerous turbulence models, ease of use, portability, parallel processing capability, and the ability to incorporate grids with a generalized topology. This particular feature makes WIND attractive for use with the GridPro grid generation package. GridPro produces structured, multi-block grids with non-overlapping block interfaces.

The focus of this effort is to investigate: 1) the application of WIND for complex flow problems; and 2) the use of multiblock, patched grid topologies. This study considers the application of WIND 1.0 to the study of two different missile configurations at angles of attack of 14° and 40° and at Mach numbers near 2.5. The generation of multiblock, patched grids using the GridPro package is discussed and results for different turbulence models are presented.

2. MISSILE CONFIGURATIONS

Two missile configurations were examined in this study. Both missiles consist of a 3-caliber ogive nose and a 10 caliber cylindrical body. Each missile has four fins, with symmetry about the pitch plane. The specific fin geometry and placement is shown in Fig. 1 and Fig. 2.
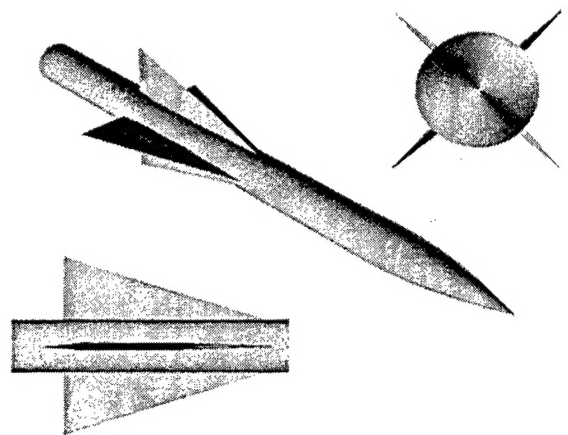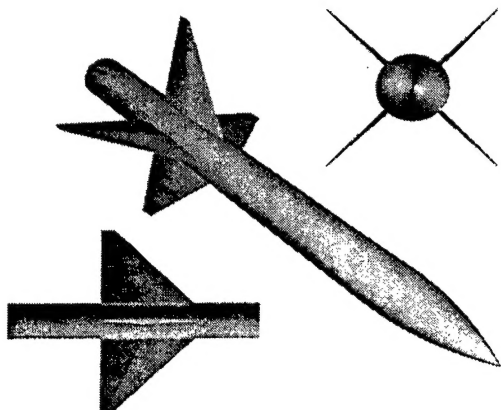

Fig. 1 Missile 1 configuration

Fig. 2 Missile 2 configuration

Missile 1 (Birch, 1996) was studied at roll angles of 0° and 45°, Mach 2.5, and 14° angle of attack with a Reynolds number of 1.12 x 10^6. Missile 2 (Stallings, et al., 1980) was studied at a roll angle of 45°, Mach 1.6 and 2.7, and 40° angle of attack with Reynolds number of 250,000.

3. GRID GENERATION

The grid generation for this investigation was done using the GridPro grid generation software. GridPro is a product of Program Development Corporation in White Plains, NY. This package is of interest because it incorporates a topology-based approach to the generation of grids. This approach emphasizes the underlying topology of the geometric shapes and of any flow features rather than focusing on the geometry of the problem. The package consists of a graphical user interface (GUI) for topology design, the grid generation software, and utilities for manipulating grids. GridPro produces multiblock, structured grids with the capability to output data in a variety of formats. An important consideration when using GridPro is that the adjacent zones abut but do not overlap. The user can also customize GridPro to output initial boundary data relevant to a particular flow solver.

The user designs the topology by constructing a coarse, unstructured, hexahedral mesh in the region of interest. The hexahedral elements become the individual blocks of the final multiblock grid. The user controls only the topological structure of the grid; the grid generator automatically calculates precise placement of grid lines. Because the gridding process is largely automatic, the user has a significant amount of flexibility in designing the fundamental topology of the grid. This flexibility includes being able to locally define the grid in regions of interest while leaving a coarser grid in regions with insignificant flow variation. After the topology

design is complete, the user invokes the grid generation software. The resulting grid for a complex shape may result in hundreds of blocks.

The utilities included with the package allow a variety of operations to the final grid. Two of particular interest are the block merging utility and the clustering utility. The block merging utility merges the (often) large number of blocks to a more manageable number. The user can control the number of grid nodes that are allowed in each block of the final configuration. Thus, the merging utility together with the initial topology design can be used as an *a priori* "domain decomposition" tool. The other utility of interest clusters grid lines to a particular surface. In practice, the grid generation package is always used to generate Euler grids and the clustering utility is used to obtain a viscous grid. This significantly reduces the time required to obtain a viscous grid.

For the missiles under consideration, the topology design required several days to construct a reasonable topology. The grids were generated using a SGI ONYX with R12000 CPUs. The grid generation generally required on the order of 6 - 8 hours of CPU time. The initial grids in each case had on the order of 375 blocks for one half of the flow volume (symmetry assumed). The number of blocks was reduced by merging to a more tractable number. The final grid configurations are listed in Table 1.

Table 1 Grid Details

Missile	Blocks	Grid Points (in millions)
1 (0° roll)	35	4.1
1 (45° roll)	42	4.3
2	26	4.2

The topology designed for the missiles did not have rotational symmetry; therefore different topologies and grids had to be generated for missile 1 at different roll angles. Examples of the topologies are shown in Figures 3, 4 and 5. Fig. 3 illustrates a close up view of the nose tip topology. A close up view of the fin topology is shown in Fig. 4. Fig. 5 shows the whole missile topology. Samples of the grids generated are shown in Figures 6 and 7. In these figures, the darker lines indicate the block boundaries and are suggestive of the topology design that was used to create the grid. For the purposes of display, the figures show coarse versions of the final grid before a viscous boundary layer was added to the grid.

4. BOUNDARY AND INITIAL CONDITIONS

In all cases, the freestream inflow condition was used on the inflow boundary, the reflection boundary condition was used on the symmetry plane, the freestream outflow condition was used on the outflow plane, and the viscous wall condition was used on the viscous surfaces of the missile body. For missile 1, the total freestream pressure was 20.628 psi and the total freestream temperature was 554.4 R. For missile 2, the static freestream pressure was 0.5637 psi and the static freestream temperature was 248.4 R. The WIND default initialization was used to initialize the flow field variables.

Runs were conducted using the following turbulence models: Baldwin-Lomax (BL), Baldwin-Barth (BB), Spalart-Allmaras (SA), and Shear Stress Transport (SST). The Baldwin-Lomax was run both with and without the option of choosing the maximum number of grid points to search for F_{max}. For the former case, maximum grid points 10 and 30 were studied (BL10 and BL30, respectively).

To avoid transient instabilities, the FIXER keyword was used. For missile 1, an initial solution was calculated at a low angle of attack and this solution was used as an initial solution for calculating the solution at a higher angle of attack. For missile 2, the TVD factor was reduced to 1, the CFL crossflow factor was set to 1, and the CFL number was reduced to .4.

5. SOLVER PERFORMANCE

Runs were conducted on Silicon Graphics Origin 2000 or Onyx platforms with multiple processors. Runs were typically conducted using 8 processors and converged solutions could be obtained in 8-12 hours. In each case, the residuals decreased by no more than 3 orders of magnitude over several thousand cycles. To test convergence, solutions were monitored until they were judged to be converged. In the case of missile 2, the loads on the body were calculated using the LOADS keyword in WIND and the solution was considered to be converged when the loads had converged and remained steady for a few hundred cycles.

The parallel performance obtained varied widely depending on the grid used. The grids used for missile 1 were reduced to the final number of blocks while trying to balance the number of nodes in each block. Speedup factors as high as 7.5 were obtained using 8 processors and as high as 14 were obtained for 16 processors. The performance for missile 2 was considerably worse – speedup factors for 8 processors was around 5 – because

the block merging process was done so as to minimize the number of blocks, rather than to optimize for parallel performance. An example of the best parallel performance is shown in Fig. 8.

6. RESULTS

Quantities of interest for the study are the pressure coefficient at different stations on the body and fins as well as pitot pressure profiles of the outer flow field at several axial stations. The data presented show examples of the results for missile 1 that were obtained using WIND. The stations and data displayed in the figures were selected with the intention of eventually comparing the computational data with experimental data.

The pitot pressure prediction for missile 1 shown in Fig. 9 for roll angle 0 and at axial station X/D = 11.5 show similar results for the SA, BB, and SST models. The BL10 turbulence model predicts a smaller, more intense primary vortex. In addition, this model predicts a more structured solution near the body of the missile. The BL turbulence model predicts a solution that more closely resembles the predictions of the one- and two-equation models. Comparison of surface pressure predictions on the missile body at various axial stations shows minimal variation between the different turbulence models with the exception of BL10. Sample comparisons with the experimental data are shown in Figures 10 and 11 for roll = 0°.

A reasonable result could not be obtained for missile 2 at the desired angle of attack. Attempts were made to improve the stability of the problem by improving the grid quality and density, reducing the CFL number, and using smoothing options available with WIND. In every instance, the run aborted due to singularities in the flow field. It is most likely that the difficulty was due to the extreme 40° angle of attack. Runs using the same grid, the same flow conditions, but at 20° angle of attack converged successfully.

7. CONCLUSIONS

The WIND flow solver has been demonstrated to be an efficient tool for increasing and extending the predictive capability of researchers in computational fluid dynamics. WIND has proven to be particularly useful for flow problems with complex geometry although extreme flow conditions caused some difficulties. The ability of WIND to accommodate multi-block, patched grids enabled the use of the GridPro grid generation software. This software package was found to generate high quality structured grids with modest

effort and is well suited for use on Army missile configurations. The Spalart-Allmaras turbulence model was found to perform quite well in comparison with the other models used in this study. In particular, no benefit was seen to result from the application of higher order models.

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Stallings, R., Lamb, M., Watson, C., "Effect of Reynolds Number on Stability Characteristics of a Cruciform Wing-Body at Supersonic Speeds", NASA TP 1683, July 1980.
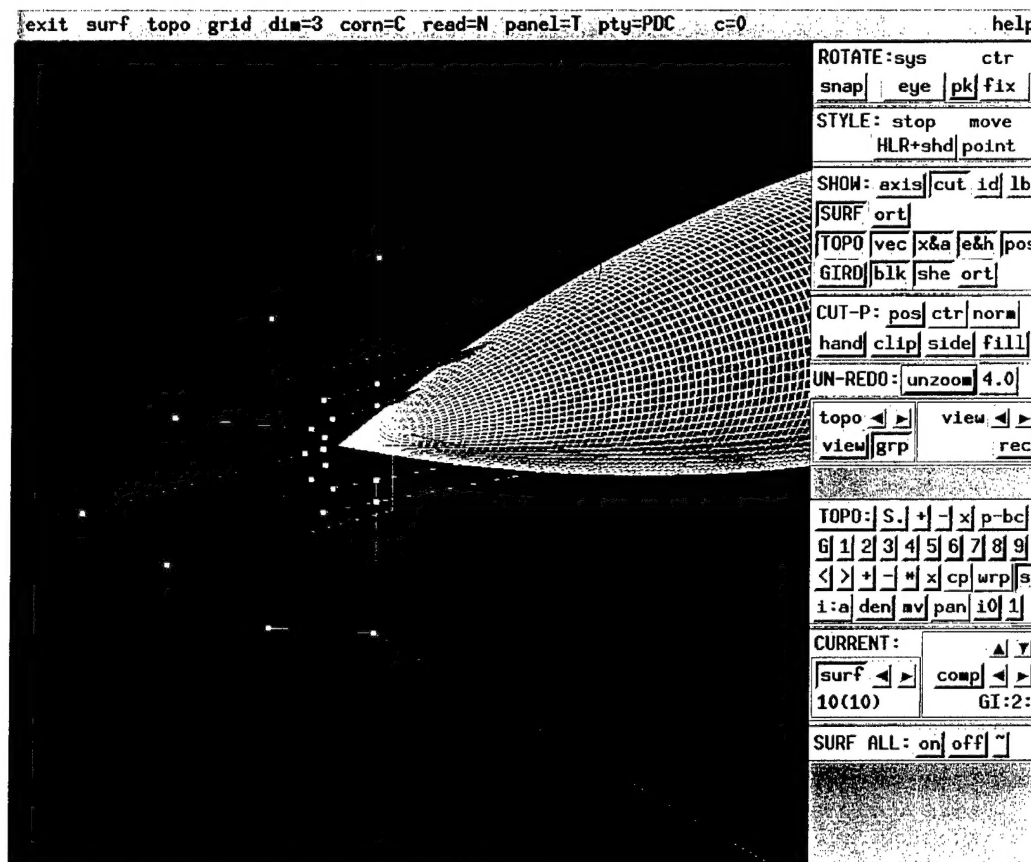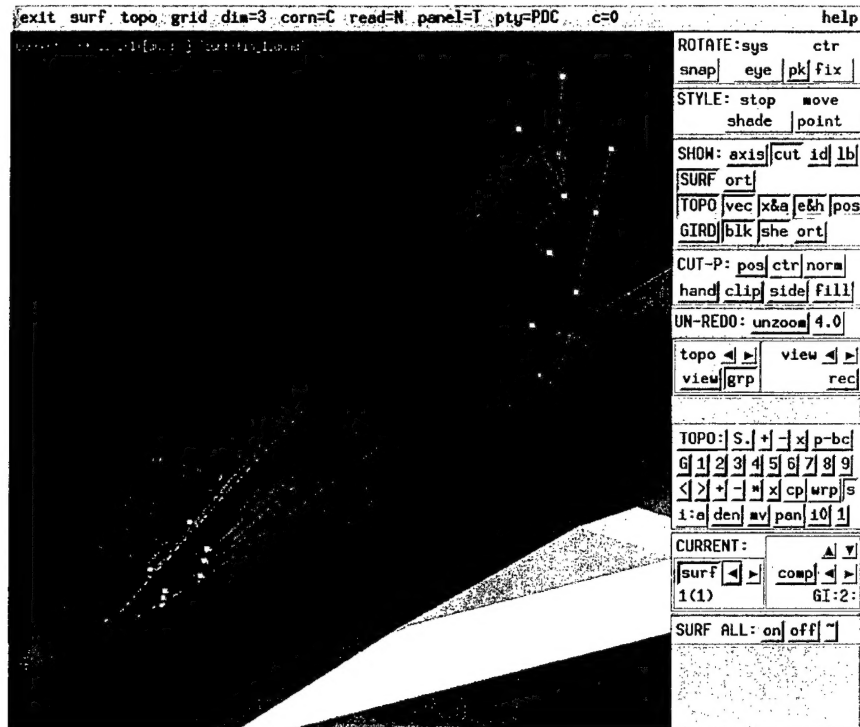
Fig. 3 Nose tip topology
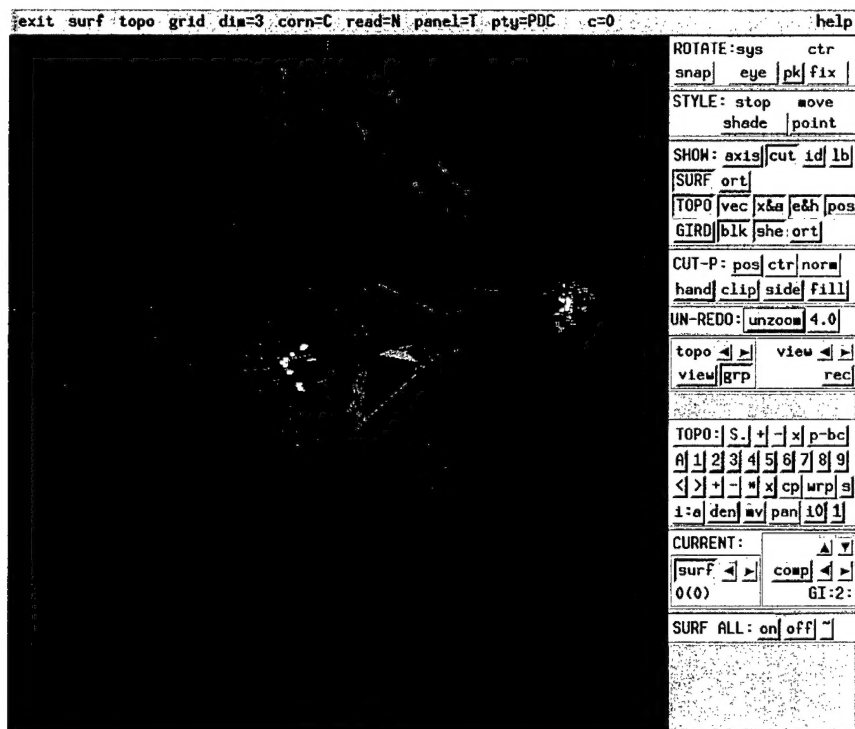
Fig. 4 Fin topology
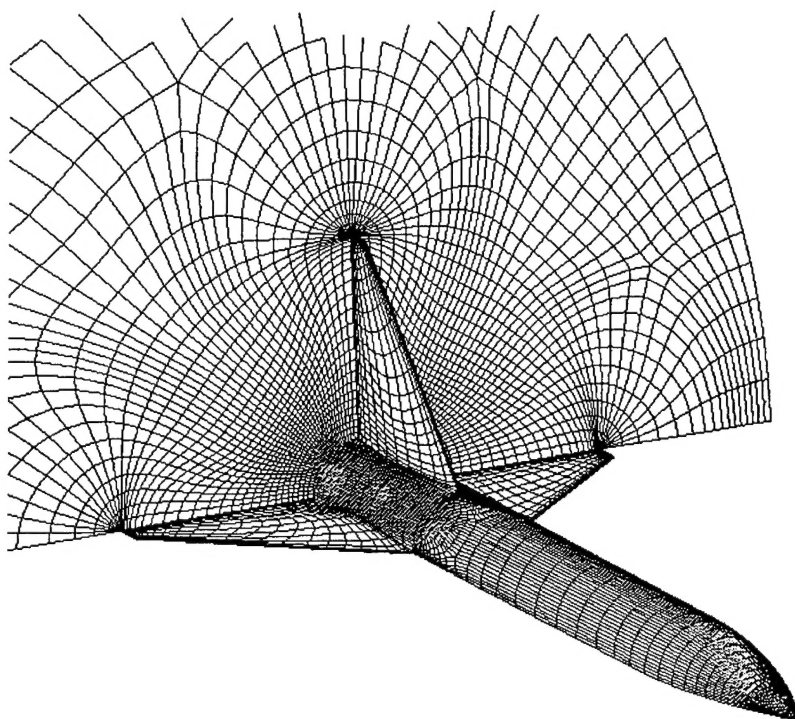

Fig. 5 Missile topology

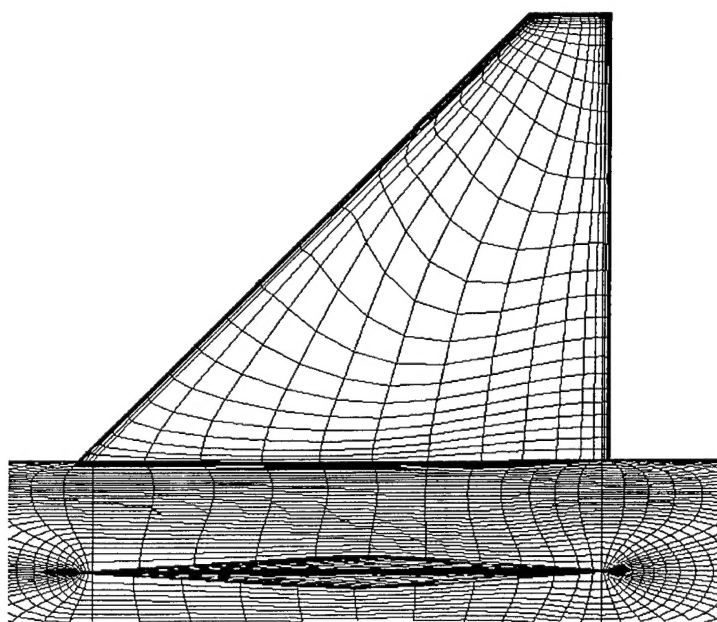Fig. 6 Example of a coarse Euler grid for missile 1
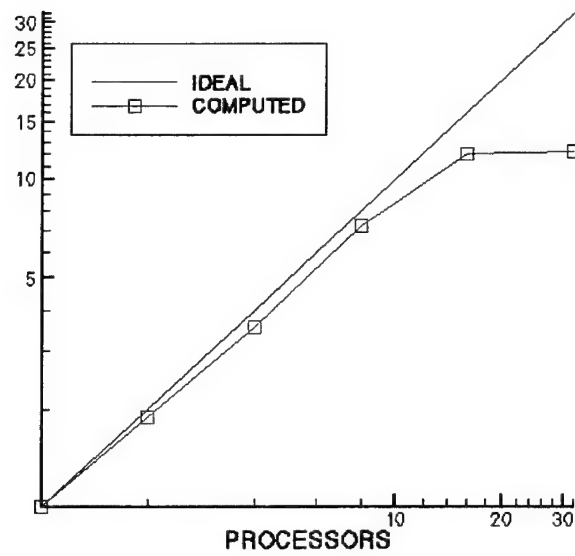

Fig. 7 Fin grid

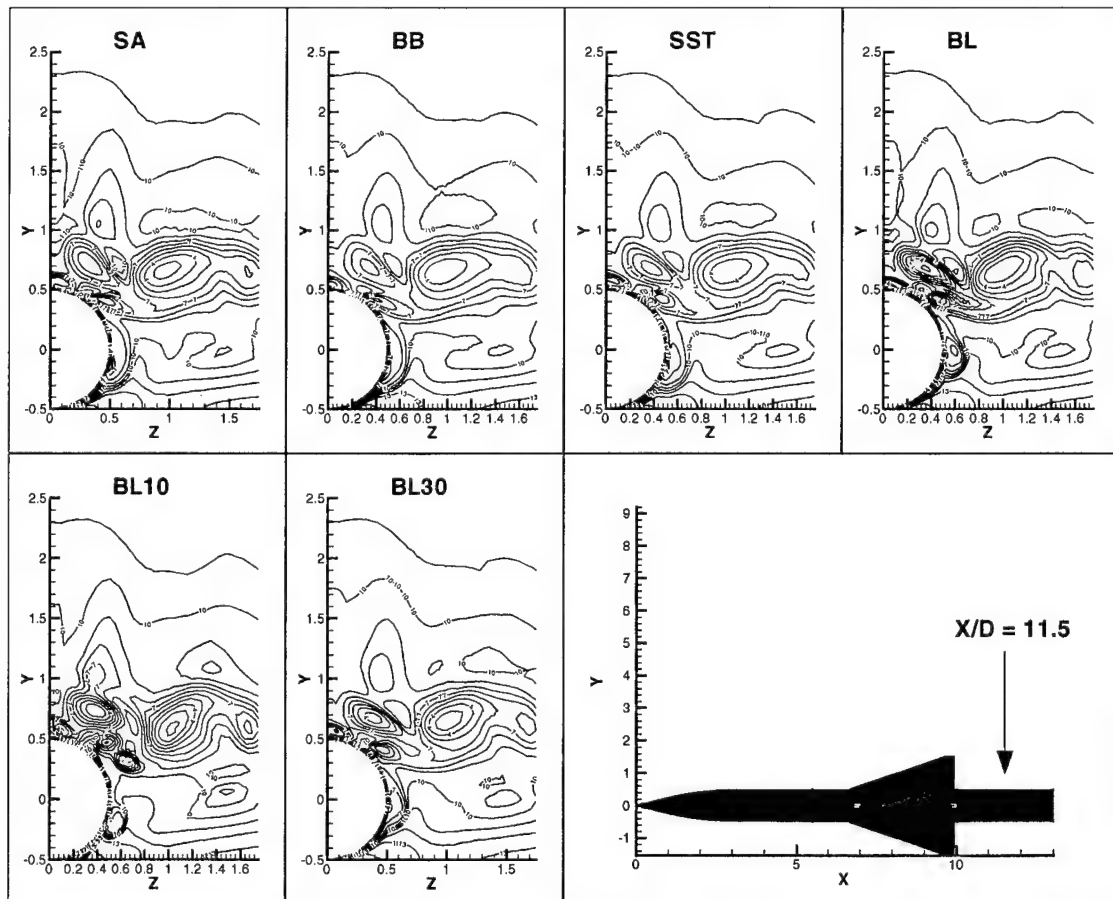Fig. 8 Measured speedup using grid for missile 1, roll angle 0

Fig. 9 Comparison of pitot pressure predictions at X/D = 11.5 on missile 1
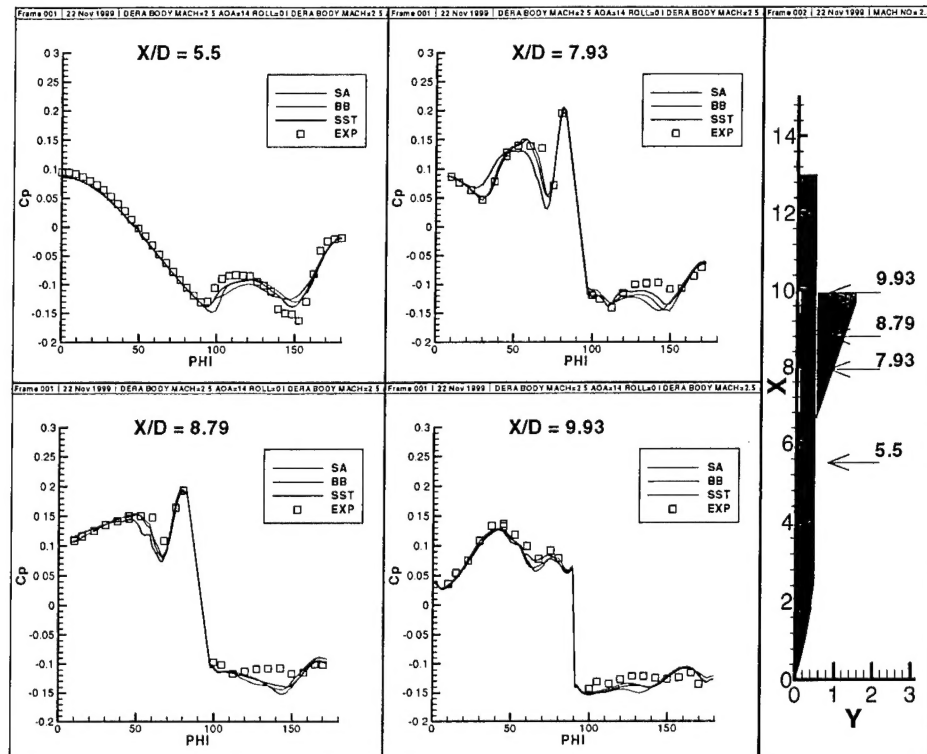
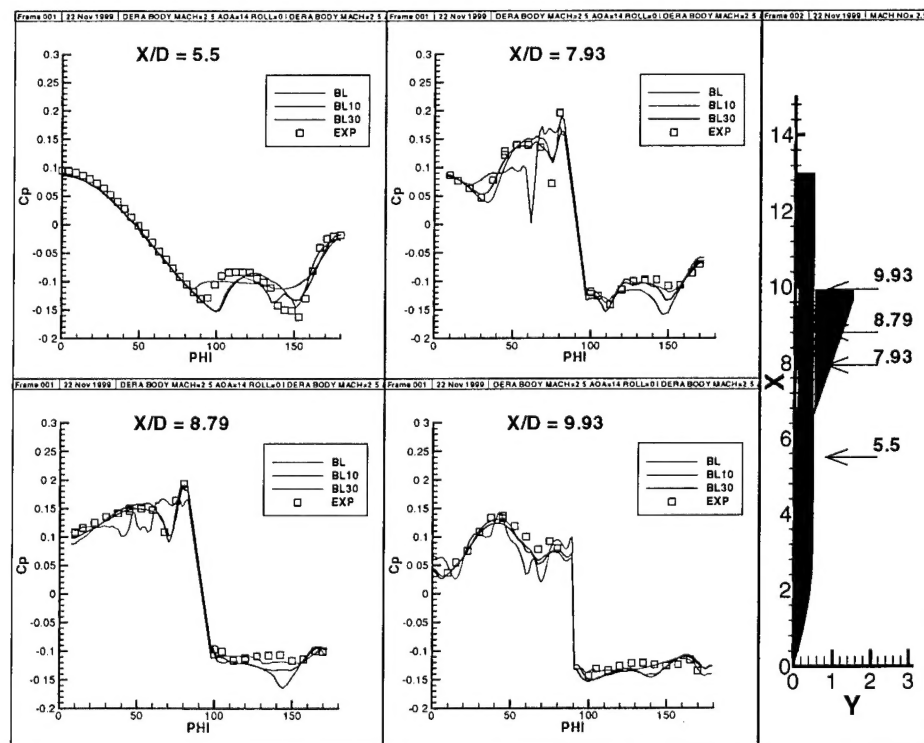Fig. 10 Comparison of surface pressure predictions on the body of missile 1

Fig. 11 Comparison of surface pressure predictions on the body of missile 1

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